EARTHQUAKES

Scientist still do not appear to understand sufficiently that all earth sciences must contribute evidence toward unveiling the state of our planet in earlier times, and that the truth of the matter can only be reached by combing all this evidence...It is only by combing the information furnished by all the earth sciences that we can hope to determine 'truth' here , that is to say, to find the picture that sets out all the known facts in the best arrangement and that therefore has the highest degree of probability. Further we have to be prepared always for the possibility that each new discovery, no matter what furnishes it, may modify the conclusion we draw.

Alfred Lothar Wegener In the
***Origins of Continents and Oceans* (1929)**

"We cannot prevent earthquakes; however, we can significantly mitigate their effect by identifying hazards, building safer structures and providing education on earthquake safety"

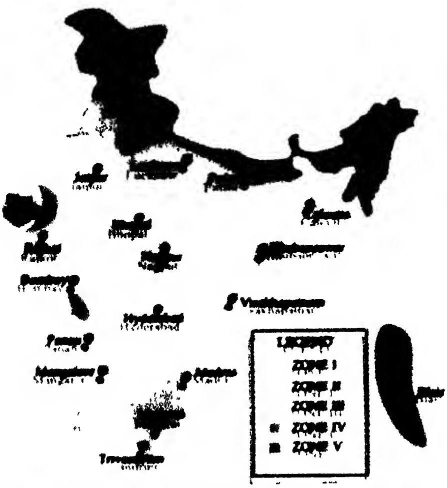
"Earthquakes are part of a global tectonic process that generally occurs well beyond the influence or control of humans"

Earthquakes are considered to be one of the worst natural hazards causing widespread disaster and loss of human lives. The impacts of earthquakes normally cover large areas causing deaths, injuries and destruction on a massive scale. Though they have high consequences, they have low probability. For this reason the post-disaster response takes place on ad-hoc basis without any prior preparedness. Destruction can be so swift and sudden that people have no time to escape. In the last two decades (1980-2000) 26 major earthquakes have occurred in different parts of the inhabited Earth, which killed about 1,50,000 people.

The most recent devastating earthquake in India was in Gujarat. On 26 January 2001at 8:46:41 IST at a latitude of 23.40, longitude 70.32, Depth 23 6 km an earthquake suddenly struck in western Gujarat when the President was saluting the Republic on its 51st anniversary. This changed the joyous mood of the nation into a national sorrow. The earthquake was the most powerful to strike India since August 15, 1950 when an 8.5 magnitude earthquake killed 11,538 people in northern part of Assam State. In 1897 the

earthquake that occurred in the Shillong plateau had a magnitude of 8.7. These two earthquakes were so intense that rivers changed their courses. What is more, ground elevation changed permanently and stones were thrown upward.

According to India Meteorological Department the Earthquake of 26 January 2001 measured 6.9 on the Richter scale but the US Geological Survey put its magnitude at 7.9. There were at least 83 after-shocks, several measuring upto 5-6 magnitude in the 10 hours after the earthquake. The earthquake, close to the border with Pakistan, caused high rise buildings to sway far away in the capital, New Delhi and was felt away in Nepal and in Bangladesh. The epicentre was near Bhuj, a desert town of 1,50,000 people in Gujarat. Some experts compared the magnitude of this earthquake to the detonation of 60 megaton hydrogen bomb. It will take years to properly rehabilitate the affected ones



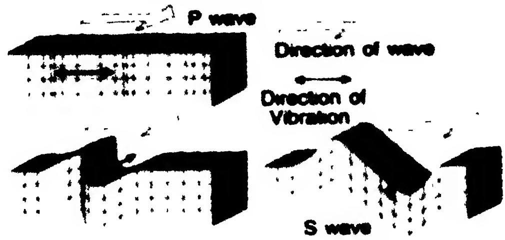
Seismic Zonation map of India(IS: 1983-1984) Reproduced from *Earthquakes in India*, Department of Science & Technology, Govt. of India, 1999), Original Source. India Meteorological Department, New Delhi

Nobody can remain without being affected from such an earth-shaking disaster. Everytime we confront an earthquake it leaves a host of more or less similar questions in our minds Why earthquakes occur? Can earthquakes be predicted? Why earthquakes are confined to certain regions of the Earth's surface? Why the magnitudes vary? Can the collapsing of the buildings be prevented? When was the last earthquake? When and where there will be a next earthquake? What do we mean by focus or an epicentre of an earthquake? How the damage can be minimised?

Because of their tremendous devastating consequences earthquakes have been the subject of legends and myths. In the past, different cultures in different times had taken recourse to legends to explain the mystery of the 'shaking earth'. Though scientists are yet to fully understand the earthquake processes but they have developed a framework which provide explanation for

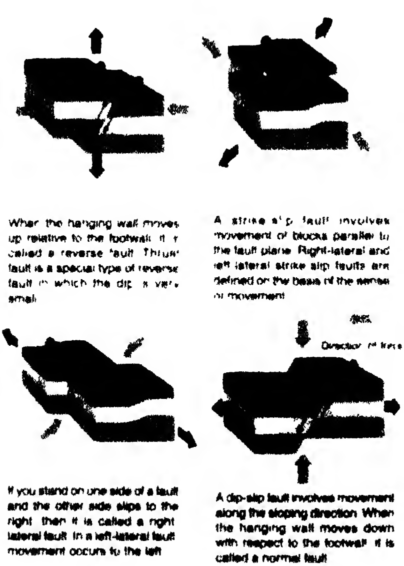
spatial and temporal recurrence patterns of global earthquakes.

An earthquake may be defined as the shaking of the Earth's surface as a result of the sudden release of the stresses built up in the Earth's crust (the solid, rocky outer portion of the Earth), this may range from mild tremor to a large-scale earth movement causing extensive damage over a wide area. The point at which the earthquake originates is known as the seismic focus and the point on the Earth's surface directly above this is the epicentre or hypocenter. The location of the epicentre is expressed by latitude and longitude.



Propagation of seismic waves through the Earth(Reproduced from *Earthquakes in India*). *Original source:* Bolt, B.,(1993) Earthquakes, W H. Freeman and Company, New York

Most earthquakes occur along faults (fractures or breaks in the crust). A fault is a fracture or break in the Earth's crust along which movement occurs. If the movement has a major vertical component the fault is called a normal fault, where rocks on each side have moved apart or a reverse fault where one side has overridden the other. A low angle reverse fault is called a thrust. A lateral fault or tear fault occurs where the relative movement is sideways. Faults may range in length from a few millimetres to thousands of kilometers. Most faults produce repeated displacements over geologic time.



Fault models Reproduced from *Earthquakes in India*, Department of Science & Technology, Govt. of India, 1999), Original Source: Earthquakes in Japan, 1996, Science & Technology Agency of Japan, Tokyo

An earthquake generates vibrations that propagate within the earth or along its surface–two types of body

waves that travel within the earth and two types of surface wave. The physics of seismic waves is rather complex. The primary or longitudiual body waves or P-waves impart a back-and-forth motion to rock particles along their path. They travel at speeds between 6 km per second in the surface rock and 10.4 km per second near the Earth's core. Secondary or transverse body waves or S-waves cause rock particles move back-and forth perpen-dicular to their direction of propagation. They travel at between 3.4 km per second in surface rock and 7.2 km per second near the core. The surface waves consist of Rayleigh waves and Love waves. Rayleigh waves, named after LordRayleigh (1842-1919) who predicted them, travel over the surface of an elastic solid giving a elliptical motion to rock particles and have the strongest effect on distant seismograph. The Love wave, named after Augustus Eward Hough Love (1863-1940) displace particles perpendicularly to the direction of propagation and have no longitudinal or vertical component.

P-waves are the first to cause vibration of a building. After P-waves comes the S-waves, which cause structure to vibrate from side to side. As building are more easily damaged from horizontal motion than from vertical motion P-waves are the most damaging. Rayleigh and Love waves arrive last. While P and S-waves mainly cause high frequency vibrations, Rayleigh and Love waves cause low frequency vibrations. The resulting vibration of the ground and building caused by body and surface waves is rather complex— hard, gentle, long, short, or rolling Seismic waves travel at different speeds in different types of rocks.

According to plate tectonics theory the Earth's outermost layer or the crust is regarded as a jigsaw of rigid major and minor plates up to hundreds of kilometers thick, which move relative to each other, probably under the influence of convection currents in the mantle below. The whole globe is divided into a number of seismic

Boundaries of major tectonicplates and distribution of earthquakes(Reproduced from *Eartquakes in India*) *Original source:* Judson, S and Richardson, S.M.(1995). ***Earth: An Introduction to Geologic Change***; Prantice Hall, Engeswood, New Jersey

plates. The major plates are: Antartic Plate, Eurasian plate, Australian Plate, Philippine Plate, Juan De Fuca plate, North American Plate and Cocos Plate, Pacific Plate, Caribean Plate, Nazca Plate, South American Plate, Scotia Plate, Arabian Plate, African Plate, Indian Plate. The Indian and Australian plates together are called Indo-Australian Plate. Major landforms occur at margins of the plates where the plates are colliding or moving apart. The plates move very slowly and sometimes slide past each other. Most severe earthquakes occur when the plates meet. Sometimes the edges of the plates grip each other and cannot move, so pressure builds up. Suddenly the plates slip and lurch past each other making land shake violently. In the process the Earth's crust gets ruptured causing huge faults Once faults are formed they become areas of weakness and earthquakes which are means of releasing energy to remove accumulated strain are mostly confined to the existing faults. New faults are caused when the strain is released at places away from the existing ones.

The concept of the continental drift was first put forward in 1915 by the German geophysicist Alfred Lothar Wegener (1880-1930) and the theory of plate tectonics was formulated by the Canadian geophysicist John Tuzo Wilson (1908-93) in 1965 and has gained widespread acceptance among earth scientists.

Today we see the continents are separated by oceans. But there was a time (say some 225 million years ago) when there was only one single continent called Panagea The rest of the Earth's surface was occupied by the ocean Then some 200 million years ago Panagea split into two major continents called the Laurasia (which included what are now North America and Eurasia) and Gondwanaland (which included what are now India, Australia, Africa, South America and Antarctica). Once separated these two major continents started drifting in different directions over the surface of the Earth These two continents further split into a number of smaller land masses and continued to move in different directions The Indian Plate or the India landmass travelled at a speed say a few meters per century for millions of years before it collided with Asia or the Eurasian plate about 40-50 million years ago. The collision was marked by the formation of the Himalayas.

While earthquake can strike any location at any time but the history of earthquake shows that there are three large zones of the Earth where the occurrence of earthquakes is more frequent than in other places. The first zone is the circum-Pacific Seismic belt, the world's, greatest earthquake belt where about 81 percent of the world's largest earthquakes occur. The belt which is found along the rim of the Pacific Ocean, extends from Chile, northward along

the South American coast through central America, Mexico, the West Coast of the USA and the southern part of Alaska, through the Aleutian islands to Japan, the Philippine Islands, New Guinea, the Island group of the southwest Pacific, and to New Zealand. The second important belt, the Alpide, accounts for about 17 percent of the world's largest earthquakes. It extends from Java to Sumatra, through the Himalayas, the Mediterranean and out into the Atlantic. The third important belt follows the submerged mid-Atlantic Ridge.

In the Indian plate faults are created when this rubs against the Eurasian plate. The Allabund fault, on which the epicentre of the earthquake of 26 January 2001 fell, has witnessed major earthquakes in the past. The earthquake of 1819 had a magnitude of 8.0 on the Richter scale and located 20 km northof Bhuj. The Allabund fault, which is a minor fault has history of earthquakes. Since 1956 eighty-five earthquakes of varying intensities have been recorded from the same area.

A large part of India is liable to a wide range of probable maximum seismic intensities Earthquakes in India are caused by the release of elastic strain energy created and replenished by the stresses from the collision between the Indian plate and the Eurasian plate. The most intense earthquakes occur on the boundaries of the Indian plate to the east, north and west. Two premier government organisations viz. India Meteorological Department (IMD) and Geological Survey of India (GSI) are primarily responsible for monitoring the earthquake hazard in the country The IMD is the national agency for detection and locating earthquake and for the evaluation of seismicity in different parts of the country The first seismological observatory was established by IMD in 1898 in Kolkata (then Calcutta). Today it has observatories round the country The country has been divided into five different seismic zones, zone I – zone V with respect to the severity of the earthquake on a decreasing scale—Zone I (no risk); Zone II (low risk); Zone III (moderate risk); Zone IV (high risk) and Zone V (very high risk) A catalogue prepared by the India Meteorological Department has listed about 1200 earthquakes known to occur in India

The major earthquakes (magnitudes are given in brackets) that hit India in the 20th century are given here :-

April 4, 1905	In Kangra (8.0) in Himachal Pradesh. It killed thousands.
January 15, 1934	Near Bihar-Nepal border (8.3). It caused extensive damage in Kathmandu, Patna and Darbhanga.

June 26, 1941	Andaman Islands (8.1)
August 15, 1950	Assam (8.5)
January 19, 1975	Kinnaur and Lahul Spiti in the Himalayas (6.2)
August 21, 1988	Near Bihar-Nepal Border (6.5). It killed 900 people.
October 20, 1991	Uttarkashi (6.6). It killed over 1600 people.
September 30, 1993	Latur, In Maharashtra, (6.3). It killed more than 10,000 people.
May 22, 1997	Jabalpur region, Madhya Pradesh (6.0). About 40 people were killed.
May 29, 1999	Chamoli Area in Uttaranchal (then Uttar Pradesh) (6.8). Caused extensive damage.

A large earthquake is often followed and preceded by tremors of different intensities. To describe this phenomenon seismologists have coined three terms—foreshock, mainshock and aftershock. In any cluster of earthquakes, the one with the largest magnitude is called the mainshock, anything before it is called foreshock and anything after it is called an aftershock

A list of some of the significant earthquakes in India and their location

Date	Epicentre	Magnitude
1819 June 16	Kutch, Gujarat	8 0
1869 Jan 10	Near Cachar, Assam	7.5
1885 May 30	Sopor J&K	7 0
1897 June 12	Shillong plateau	8 7
1905 April 4	Kangra, Himachal Pradesh	8 0
1918 July 8	Srimangal, Assam	7 6
1930 July 2	Dhubo Assam	7 1
1934 Jan 15	Bihar Nepal Border	8.3
1941 June 26	Andaman Islands	8 1
1943 Oct 23	Assam	7.2
1950 Aug 15	AP-China Border	8 5
1958 July 21	Anjar, Gujarat	7.0
1957 Dec 10	Koyna. Maharashtra	6 5
1975 Jan 19	Kinnaur, Himachal Pradesh	6.2
1988 Aug 6	Manipur- Myanmar Border	6 6
1988 Aug 21	Bihar-Nepal Border	6.4
1991 Oct 20	Uttarkashi	6.6
1993 Sept 30	Letur-Osmanabad, Mah	6.3
1997 May 22	Jabalpur, MP	6.0
1999 March 29	Chamoli, Uttar Pradesh	6.8
2001 Jan 26	Bhuj	7.8

Eathquakes induced by human activities like injection of fluids into deep wells for waste disposal and secondary recovery of oil and the use of reservoirs for water supplies have been documented in a few places in the USA, Japan and Canada. The most well-known human activity induced earthquake resulted from fluid injection at the Rocky Mountain Arsenal near Denver, Colorado. This happened in 1967. Its magnitude was 5.5 and which was followed by smaller earthquakes.

The earthquakes having the same magnitude on the Richter scale may vary in damage from place to place. The extent of damage that an earthquake can cause may depend on more than one factor. The depth of the focus may be one factor. Earthquakes can be very deep and in such case surface damage may be less. The earthquake of 26 January 2001 was relatively shallow; less than 25 Km deep. The earthquake in Garhwal in March 1999 was also shallow. Earthquakes occur in the crust or upper mantle, which ranges from the Earth's surface to about 800 km. Surface rupture occurs when movement on a fault deep within the Earth breaks through the surface.

During an earthquake one feels a swaying or small jerking followed by a small pause, and then a more vigorous rolling or jerking motion. For small earthquakes the ground shaking usually last only a few seconds but the ground may continue to shake for more then a minute in a major earthquake. The ground continued to shake for about three minutes on the occasion of the 1964 Alaska earthquake whose magnitude was 9.2. The duration of ground shaking resulting from earthquake depends on various factors like distance from the epicentre, the condition of the soil and if one stands on a building then the height of the building and the type of material it is constructed from.

Damages by earthquake primarily occur due to collapse of structures or buildings. The damage can be substantially minimised by incorporating proper safety measures. Everytime an earthquake strikes, the need to enact proper laws to make earthquake safety norms binding on buildings is highlighted. Codes and guidelines for earthquake resistant building have been developed by the Bureau of Indian Standard's code of practice. They were first developed in 1962 and 1967. Subsequently they were revised, updated and expanded every few years until 1993. But the code is only recommendatory in nature. So their implementation has not been satisfactory perhaps with exception of some government organisations. Such legislations should include amendment to the town and country planning Act, Master plan development rules, empowering development authority to exercise necessary control and incorporation of safety requirements in building bylaws of local bodies.

World wide earthquake frequency		
Descriptor	Magnitude	Average annually
Great	8 and higher	1
Major	7-7.9	18
Strong	6-6.9	120
Moderate	5-5.9	800
Light	4-4.9	6,200 (estimated)
Minor	3-3.9	49,000(estimated)
Very Minor	<3 0	Magnitude 2-3 about 1,000 per day Magnitude 1-2 about 8,000 per day

Fatalities can be reduced if the aftermath relief work can be organised timely and efficiently. This requires cranes, blowtorches, sniffer dogs and acoustic devices, doctors particularly orthopaedic surgeons and blood supplies. Then we need to organise temporary shelter, blankets and food For managing the post-disaster scenario most effectively we require to place more emphasis on the following:

- extensive public awareness campaigns especially in rural areas
- greater involvement of NGOs and private sectors
- effective communication system

Recent experiences have demonstrated the utility of Ham Radio in establishing contacts with the affected area where normal communication network breaks down. Efforts are to be made to popularise Ham Radio Internet can help us in making all kinds of relevant information available from different parts of the globe without any time lag.

Large earthquakes cause violent motions of the Earth's surface. Sometimes they cause huge sea waves that sweep up on land and add to the general destruction, such waves often occur in the Pacific Ocean because of many earthquakes there.Geologists use a Japanese term 'tsunami' for these destructive waves. Tsunamis are often mistaken for tidal waves. Tsunamis are not caused by the tidal action of the Moon and the Sun. The wave is not very high in mid-ocean but the distance between wave crests can be very long, more than 60 miles It begins to rise as it nears the coast, sometimes growing to about 76m. The tsunami smashes onto the shore destroying buildings and carrying boats and ships far inland. Tsunamis are also caused by volcanic eruptions. The speed at which the tsunami travels decreases as water depth decreases. In the mid-Pacific where the water depths reach 3miles, tsunmai can travel at the speed more than 430 miles per hour. While.the destruction caused by the ground shaking is confined to the vicinity of the

epicentre but tsunamis cause destruction both locally and at very distant location from the area of tsunami generation.

The recurrence of earthquakes is not very unusual. Approximately once in every 87 seconds somewhere in the world, the Earth shakes slightly. These tremors are strong enough to be felt, but cause no damage. On an average every year the earth witnesses 800 earthquakes with a magnitude of 5.0-5.9 on the Richter Scale but without causing any damage. In addition to these every year there are 18 major earthquakes measuring 7.0 to 7.9 on the Richter scale and one great earthquake measuring 8.0 and above Fortunately, as scientists claim, most of these occur in uninhabited or virtually uninhabited areas.

But then there are earthquakes which appear to be unusual to scientists. For example, three earthquakes exceeding a magnitude of 8 occurred in New Madrid (near Missouri in the US) within a span of about 7 weeks (December 16, 1811, Feb. 7 and 23, 1812). On January 22, 1988 three quakes of magnitude of more than 6 occurred in a span of 12 hours in Tennant Creek, Australia.

The magnitude of an earthquake is measured on the basis of the ground wave recorded by seismograph. Seismograph is an instrument that records ground oscillation Most modern seismographs are based on the inertia of delicately suspended mass and depend on the measurement of the displacement between the mass and a point fixed to the earth. Others measure the relative displacement between two points on earth. Necessary correction for the epicentral distance from the recording station needs to be applied. The strength of an earthquake is measured on the basis of the maximum amplitude of the signal recorded by a seismograph and how far the instrument is stationed from the earthquake.

A seismometer may be a pendulum or mass mounted on a spring. A seismogram is the record produced by seismographs used to calculate the location and magnitude of an earthquake. On a seismogram, the horizontal axis represents time measured in seconds and the vertical axis represents the ground displacement usually measured in millimeters. The movement of a seismometer can be converted into a seismogram in several ways viz.,

The earliest seismoscope invented by Chinese philosopher Chang Heng in A.D. 132

a pen drawing on ink line on paper revolving on a drum; a light beam making a trace on a moving photographic film and electromagnetic system generating a current that is electronically records on tape. In the absence of an earthquake the seismogram is just a straight line except for small wriggles caused by local disturbance or noise and the time marker. The earliest seismoscope was invented by the Chinese philosopher Chang Heng in AD132. The device, a large urn with eight dragonheads on its outside facing the eight principal directions of the compass. The urn was attached to a base. Below each dragon head was a toad with its mouth opened toward the dragon. In the event of an earthquake one or more of the eight dragon-mouths would release a ball into the open mouth of the toad sitting below The direction of the shaking determined which of the dragon released its ball. What was inside the urn is not known

The Richter scale, named after the US physicist Charles F. Richter of the California Institute of Technology was first introduced in 1935. Richter evolved the scale from patterns he discovered by studying hundreds of earthquakes The scale starts at one and has no upper limit. However, the largest known shocks have had magnitudes in the 8.8 to 8 9 range As the Richter scale has a logarithmic basis, each unit is 10 times greater than the one before. The Richter scale does not measure an earthquake's effects. It gives the measure of its strength in terms of the energy released as measured by a seismograph. The earthquake of highest magnitude till date in the country is of 8 7 on the Richter scale which was recorded in the Shillong Plateau on June 12, 1897 Richter magnitudes effects are confined to the vicinity of the epicentre.

The classification of earthquakes based and the magnitude on the Richter Scale.

Less than 2.0	Generally not felt, but recorded
2.0 - 2.9	Potentially perceptible
3 0 - 3 9	Felt by some
4 0 - 4.9	Felt by most
5.0 - 5.9	Damaging shocks
6.0 - 6.9	Destructive in populated regions
7.0 - 7.9	Major earthquakes; inflict serious damages
Greater than 8.0	Great earthquakes; causes extensive destruction near epicentre

It was found that the method developed by Richter for measuring the magnitude was strictly valid only for certain frequency and distance ranges. So to take advantage of the growing number of globally distributed seismograph stations new magnitude scales like body-wave magnitude (Mb), surface wave magnitude (Ms) and moment

magnitude (Mw) were developed. These scale were basically extension of the original idea developed by Richter. The moment magnitude gives most reliable estimate of earthquake size. Moment is a physical quantity proportional to the slip on the fault times the area of the fault surface that slips. The moment which can be measured from seismograms and also from geodetic measurements is related to the total energy released in the earthquake. Unlike other magnitude scale the moment magnitude gives an estimate of the size of the earthquake that is valid over the complete range of magnitudes.

How seismologists give a Richter magnitude to earthquakes that occurred prior to about 1880s (i.e. before modern seismographs came into use)? To do this seismologists look at the physical effects like faulting, landslides, sandblows or river channel change and also human effects (where records are available) like the area of damage or how strongly a quake was felt and compare them to modern earthquakes. As many assumptions need to be made for comparison different seismologists can get widely varying magnitudes from using different assumptions. So there is no wonder that many of the old earthquakes have big difference in the magnitudes assigned to them

'Magnitude' and 'Intensity' are two ways of expressing the strength of an earthquake. The magnitude on the Richter scale is a measure of the seismic energy radiated by an earthquake The intensity is a measure of the damage caused by the earthquake The intensity measurement is based on observed effect. For intensity measurement the 12-point graded Modified Mercalli Intensity scale is widely used. A Grade-I earthquake is not felt except by a very few people under specially favorable conditions. An earthquake registering five on the Mercalli scale is defined as having had furniture to shake, many may wake up, wall plaster cracks, dishes and windows break, light objects overturn and pendulum clock can stop but causing little or no damage. But an earthquake measuring 12 on the Mercalli scale would destroy all man-used objects and create new topography by forming new lakes and other major changes The most devastating earthquake in recorded history was in China's Shaanxi province in 1556. It possibly measured nine on the scale and it killed 830,000 people.

In the late 1880s, John Milne, James Ewing and Thomas Gray developed a compact seismometer that could be installed in various locations around the globe. These instruments helped to gather the earliest data on geographic distribution of earthquakes and this in turn led to recognition of plate boundaries.

The following three developments in the second half of the 20th century helped major advanced in seismology :

- The establishment of a network of 120 seismic stations by the US Govt. in the 1960s. The network was primarily

established to detect underground nuclear test.

- the development of the theory of plate tectonics which helped to develop a framework for the basic dynamic of earthquakes.
- the development of computer technology that made possible to analyses large amount of data.

Modified Mercalli Intensity Scale

i. Not felt except by a very few under especially favorable circumstances

ii. Felt only by a few persons at rest, especially on upper floors of buildings Delicately suspended objects may swing

iii. Felt quite noticeably by persons indoors, especially on upper floors of buildings Many people do not recognize it as an earthquake Standing motor cars may rock slightly Vibration similar to the passing of truck Duration estimated

iv. Felt indoors by many, outdoors by few during the day At night, some awakened Dishes, windows, doors disturbed, walls make cracking sound Sensation like heavy truck striking building Standing motor cars rocked noticeably.

v. Felt by nearly everyone, many awakened Some dishes, windows broken unstable objects overturned Pendulum clocks may stop

vi. Felt by all many frightened Some heavy furniture moved, a few instances of fallen plaster Damage slight

vii. Damage negligible in building of good design and construction, slight to moderate in well-built ordinary structures, considerable damage in poorly built or badly designed structures; some chimneys broken Noticed by persons driving motor cars

viii. Damage slight in specially designed structures, considerable in ordinary substantial buildings with partial collapse Damage great in poorly built structures Fall of chimneys, factory stacks, columns, monuments, walls Heavy furniture overturned

ix. Damage considerable in specially designed structures, well-designed frame structures thrown out of plumb Damage great in substantial buildings, with partial collapse Buildings shifted off foundations

x. Some well-built wooden structures destroyed, most masonry and frame structures destroyed with foundations. Rails bent

xi. Few, if any (masonry) structures remain standing Bridges destroyed Rails bent greatly

xii. Damage total. Lines of sight and level distorted Objects thrown into the air.

Despite these significant developments many gaps exist in our understanding of earthquake processes even in those locations where extensive data is available. Scientists are constantly revising their concepts. There have been two cases of accurate prediction of major earthquakes. The first one was the 1971 Blue Mountain Lake earthquake in New York. This was predicted by an Indian seismologist. The second accurate prediction was the case of the Heicheng earthquake in 1975 by a Chinese seismologist. Then the prediction for the Parkfield earthquake proved to be wrong. There is no scientifically established procedure for accurate prediction of earthquakes. Some experts tend to believe that precise earthquake predictions within narrow limits of time, location and magnitude may not be ever possible because of the complex and unreliable factors involved. This is inspite of the fact that earthquakes show a marked spatial distribution — the vast majority are located within narrow zones which correspond to the boundaries of the crustal plates. There are statistical techniques that can be used if all the necessary data are available to approximately predict when and where an earthquake will take place. But then prediction based on such methods are vague–the location can be anywhere within 200 km of a point and the time limit is 10 years. So such predictions even, if they proved to be right, are useless for disaster preparedness

While earthquakes cannot be stopped or accurately predicted but structures can be designed which can safely resist and negotiate the actions of earthquake ground motion. Earthquake resistant design of structures has grown into a true multi disciplinary field of engineering. Creating public awareness about all aspects of earthquake and post-earthquake scenario is essential.

Some common terms that one may encounter while studying about earthquakes.

active fault : a fault that is likely to have another earthquake some time in future.

aseismic : the term refers to a fault on which no earthquake has been observed.

benioff zone : a zone of earthquake epicentres distributed on well-defined planes that dips from a shallow depths to as great as 700 kilometers.

body wave : seismic waves that travel either along or near the earth's surface.

crust : it is the uppermost part of the earth. It consists of two distinct parts, the oceanic crust and the continental crust.

core : the innermost part of the earth, which is divided into an inner core, the upper boundary of which is 1,700 km from the centre

and an outer core, 1820 km thick. Both parts are thought to consist of iron-nickel alloy. The temperature may be 30000C.

dip : the angle that a stratum or fault plane makes with the horizontal.

earthquake : a shaking or trembling of the crust of the earth caused by breaking and shifting of rock beneath the surface or by underground volcanic process

epicenter : the point on the surface of the earth directly above the focus of an earthquake.

fault : a fracture in the earth's crust along which there has been displacement of rock on one side relative to the other. The displacement ranges from a few centimetres to a few kilometres and may occur in horizontal, oblique or vertical direction

fault system two or more fault sets which interconnect

fault scarp : a steep cliff formed by movement along one side of a fault.

fault trace or fault line: intersection of the fault surface with the surface of the earth or any other horizontal surface of reference

Fault throw The amount of vertical displacement of rocks due to faulting.

Fault Zone : A fault expressed as an area of numerous fractures

First motion On a seismogram the direction of ground motion as the p-waves arrives at the seismometer

Forsehocks: A tremor which precedes a larger earthquake or mainshock

Fault terrace : A step on slope produced by displacement of two parallel faults

Geodesy : The branch of science concerned with surveying and mapping the earth s surface

Geology : The branch of science concerned with the origin, structure and composition of the earth

Geophysics The branch of science in which the principles of mathematics and physics are applied to the study of the earth's crust and interior

Ground failure A general reference to land slides, liquefaction, lateral spreads and any other consequence of ground shaking.

Ground motion : The movement of the earth's surface caused by seismic waves and travel through the earth and along its surface.

Interplate coupling : It means a fault between two plates is locked and capable of accumulating stress

Isoseismal : A contour or line on a map bounding points of equal intensity for a particular earthquake.

Lithosphere : The topmost layer of the earth's structure forming the of plates that take part in the movement of plate tectonics.

Locked fault : A fault that is not slipping because of frictional resistance on the fault is greater than the shear stress across the fault. A

locked fault is expected to store strain for extended periods. The frictional resistance is eventually overcome in an earthquake.

Love wave : A type of seismic surface wave having a horizontal motion that is transverse or perpendicular to the direction of the propagation of the wave.

Mainshock : The largest earthquake in a cluster of earthquakes. The mainshock is sometimes preceded by one or more foreshocks but almost always followed by many aftershocks.

Mantle : The immediate zone of the earth between the crust and the core, accounting for 82 percent of the earth's volume. The mantle is separated from the crust by the Mohorovicic discontinuity and from the core by the gutenberg discontinuity. It is thought to consist of silicate Minerals Such as Olivine.

P-wave : The primary or the fastest seismic waves travelling away from an earthquake, consisting of a series of compressions and dilatations parallel to the direction of travel of the wave

Paleoseismic : The history of seismic events which is determined by examining the layers of rock beneath the surface and how they have been displaced by earthquake in the past.

Plate tectonics : The theory that the earth's surface consists of a number of plates or large crustal slabs whose slow but constant motion explain continental drift, mountain formation, etc.

Rayleigh wave : A surface seismic wave with retrogade, elliptical motion at the free surface. It is also know as r-wave.

Strike-slip fault : A fault on which the two blocks of rocks slide past one another.

Rupture front : The instantaneous boundary between the slipping and locked parts of fault during an earthquake.

Rupture velocity : The speed at which a rupture fault moves across the surface of the fault during an earthquake.

S-wave : A seismic body wave that shakes the ground back and forth perpendicular to the direction of propagation of the wave. It is also called shear wave.

Seismicity : The degree to which a region of the earth is subject to earthquake.

Seismic movement : A measure of the size of an earthquake derived from the area of fault rupture, the average amount of slip and the force required to overcome the stress generated by the faulting.

Seismic wave : Generated by an earthquake, seismic waves are elastic waves and they travel either along or near the Earth's surface (surface seismic waves) or through the earth's interior (body seismic waves)

seismic zone : An area of seismicity probably sharing a common cause.

seismogenic : Capable of generating earthquake.

seismogram : The chart of an earthquake as recorded by a seismograph

seismology : The branch of geology concerned with the study of earthquakes.

Seismometer : An instrument that records the intensity and duration of earthquakes and similar tremors. Strictly speaking seismograph is a term that refers to the seismometer and its recording device as a single unit.

Seismoscope : An instrument indicating only the occurrence and time of an earthquake.

Seismic constant : In building codes dealing with earthquake hazards, an arbitrarily set quantity of steady acceleration in units of acceleration of gravity, that a building must withstand.

seismic dicontinuity : A surface at which velocities of seismic waves changes abruptly

shearing stress : A stress in which the material by one side of a surface such as a fault plane, pushes on the material on the other side of the surface with a force parallel to the surface.

slip rate : The rate at which two sides of a fault are slipping relative to one another

slip : The relative displacement of formerly adjacent points on opposite sides of a fault measured on the fault surface

subduction : The process by which one crustal block descends beneath another

subduction zone : The place where two crustal blocks come together, one riding over the other

surface faulting : Displacement that reaches the Earth's surface during slip along a fault Surface faulting normally occurs with shallow earthquakes

surface wave : Seismic waves that travel along the Earth's surface for example, Rayleigh and love waves.

tectonic : Designing of, or pertaining to changes in the structure of the Earth's crust, the forces responsible for such deformation or the external forms produced.

teleseismic : Pertaining to earthquake at distances greater than 1,000km from the site of measurement.

thrust fault : A dip-slip fault in which the upper block above the fault plane moves up and over the lower block.

Isunami : A huge sea wave caused by a great disturbance under an ocean, as a strong earthquake or volcanic eruption.

tectonics: A branch of geology that deals with the Earth's crustal structure and the forces that produce changes in it.

tsunamigenic : Referring to those earthquakes, that can generate tsunamis.

tsunami magnitude : A number that is used to compare sizes of tsunamis generated by different earthquakes.

Alfred Lothar Wegener (1880-1930) was born in Berlin and he was educated at the universities of Heidelberg, Innsbruck and Berlin. He obtained his PhD in planetary astronomy. However, he became interested in the developing fields of meteorology and climatology.

In 1906 he went on his first meteorological research trip to Greenland. Subsequently he participated in several meteorologic expeditions to Greenland. In 1908 he was appointed to a lectureship in astronomy and meteorology at the University of Marburg. In 1914 he was drafted into the German army but was released from combat duty after being wounded. During the war he served in the army weather forecasting service. After the first World War he moved to a special chair of meteorology and geophysics at the University of Graz, Austria in 1924.

In 1915 Wegener produced his famous work, *Die Enstehung der Kontiente und Ozeane* which was translated in 1924 as *Origin of Continents and Oceans*. In this book he formulated his hypothesis of continental drifs. He proposed that the continents were once contiguous, forming one supercontinent, Panagea, which began to break up during the Mesozoic Era and drifted apart to form the continents we know today.


Alfred Lothar Wegener

The idea of his theory of continental drifs occurred to him in 1911 when he came across a scientific paper that documented fossils of identical plants and animals found on opposite sides of the Atlantic. He started looking for similar organisms separated by great oceans. At that time scientists explained such cases by assuming that once land bridges existed which connected far flung continents. But then Wegener observed close fit between the coastlines of Africa and South America. This prompted Wegener to speculate that perhaps the continents were once joined together. In support of his theory he produced the following four main arguments.

- the obvious correspondence between such opposite shores as those of Atlantic Africa and Latin America
- Geodetic measurements indicated that Greenland was moving away from Europe.
- A large portion of the Earth's crust is at two separate levels, the continental and the ocean floor and that the crust is made of the lighter granite floating on a heavier basalt.

There were patterns of similarities between species of the flora and fauna of the continents. Wegener also observed that the fossils found in a certain place often indicated a climate utterly different from the climate of today

Wegener's theory first met with considerable hostility, often exceptionally harsh and scathing . Wegener's theory found more scattered support after his death but majority of geologists continued to believe in static continent and land bridges. However, finally with the advances in geomagnetism and oceanography led to the full acceptance of Wegener's theory and the creation of the new discipline of plate tectonics after World War II.

Charles Francis Richter (1900-85) was born in Hamilton, Ohio USA. He was educated at the Universities of Southern California and Standford and the California Institute of Technology. In 1928 he obtained his PhD from the California Institute of Technology (Caltech). Richter was a Professor of Seismology at the Seismological Laboratory at the California Institute of Technology from 1936 to 1976. Once being asked that how he became interested in seismology Richter told · "It was really a happy accident. At Caltech, I was working for my PhD in theoretical physics under Dr. Robert Millikan. One day he called me into his office and said that the Seismological Laboratory was looking for a physicist; this was not my line, but was I at all interested"? I talked with Harry Wood who was in charge of the lab; and as a result, I joined his staff in 1927".

Richter developed his scale in 1935 to measure the strength of earthquakes. Earlier scales developed by de Rossi (1980s) and Giuseppe Mercalli (1902) used a descriptive scale defined in terms of damage to buildings and the behaviour and response of the population. So these scales could be used only in populated areas. This restriction made the scales relative to the type of building techniques and materials used. Richter wanted to devise a means of assessing them on an objective, quantitive basis rather than relying on subjective, descriptive methodology. With this view Richter was tabulating over 200 earthquakes a year in southern California during the 1930s. The scale originally formulated was a local magnitude scale to assess the size of earthquake occurring in the southern California. Today the scale in its modified from is used to measure earthquake worldwide. In 1954 Richter and Beno Gutenberg produced one of

Charles Francis Richter

the basic textbooks on seismology, *Seismicity of the Earth*. Richter loved to educate people about earthquake.

John Tuzo Wilson

John Tuzo Wilson *(1908-93)* was born in ottawa, canada. He was educated at the Universities of Toronoto and Princeton. He was the first student in Canada to study geophysics. He worked for the Geological Survey of Canada (during 1936-39) and then spent seven years in the army. He taught geophysics at the University of Toronto during 1946-74. He played a pioneering role in establishing the new discipline of plate tectonics during the early 1060s. Wilson was the first to use the term 'plate' to refer to the rigid portions into which the Earth's crust is divided. In 1963 by pointing out that the further away an island lay from the mid-ocean ridge the older it proved to be Wilson provided the earliest available evidence in support of the sea-floor spreading hypothesis postulated by Harry Hammond Hess (1906-69). Hess had proposed this hypothesis in his important paper *History of Ocean Basins* (1962). Wilson in his paper titled *A New Class of Faults and their Bearing on continental Drift* and publish in 1965 introduced the idea of a transform fault where the plates slide past each other without any creation or destruction of material. His book, *A Revolution in Earth Science,* was published in 1967.